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Getting to the Lunar Libration Points

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A number of space missions have been proposed to the Lunar Libration points (Earth-Moon Lagrange points) in the past and others arc currently under study. This paper summarizes and compares a variety of methods by which a spacecraft can bc launched from the Earth and arrive and rendezvous with onc of these points in space. The work reported here was instigated, and partially supported by, a mission concept study for a Space-home Astronomical Gravity-Wave Interferometer: Testing Aspects of Relativity and Investigating Unknown Sources (SAGITARIUS). (SAGITARIUS is a proposed Discovery-Class mission study being led by Ronald W. Hellings of JPL.) While this work was in support of this mission, the data are presented in a genera] format which will allow their application to other mission to the Lagrange points.

The five Lagrange points are commonly labeled L1 through L5, with 1.], L2, and L3 laying on the Earth-Moon line and L4 and L5 laying on a line equidistant from the Earth and the Moon, and at Lunar distance from the Earth. 1.], and L2 arc relatively near the Moon (about 60,000 km from the Moon) while L3 is at about Lunar distance from the Earth on the opposite side from the Moon. Sec Figure 1. These five points arc characterized by varying degrees of stability due to the joint action of the gravity fields of the Earth, Moon, and Sun. Missions to these points have been proposed to test/verify this stability and/or to make usc of this stability. For example, the SAGITARIUS mission requires three spacecraft at three widely separated points to remain stable relative to onc another. It is hoped that location at the three Lagrange points which arc far from the Moon (L3, L4 and L5) will satisfy this requirement without the need for significant orbit maintenance propellant and operations.

Placing a spacecraft at onc of these points can be an expensive proposition in expendable mass (propellant), injection energy, and/or flight time. The SAGITARIUS mission, as with most ncw scientific space mission, is being developed as a small, low-cost mission and so must bc concerned with keeping the overall system mass low. The direct scenario for getting to one of these Lagrange points involves the use of a Hohmann transfer orbit. That is, the launch vehicle would inject directly into a highly elliptical orbit with periapsis at about 200 km and apoapsis at Lunar (i.e., Lagrange point) distance. On reaching the vicinity of the Lagrange point, a velocity increment would be applied to rendezvous with the point. The injection energy can be characterized by the AV required to inject from a standard parking orbit (e.g., a circular orbit at an altitude of 200 km) onto the transfer orbit to the Lagrange point. This is 3135 m/s. The AV required to rendezvous with the Lagrange point from this orbit is about 830 m/s.

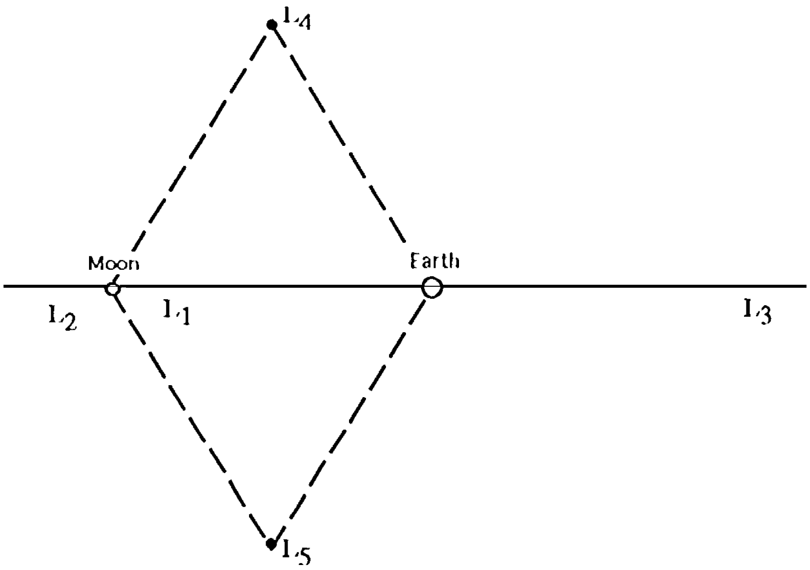

Figure 1. Earth Moon Lagrange Points.

Another method of getting to these Lagrange points would use the Moon as a swing-by gravity source to change the energy of the Earth-relative orbit with the hope of reducing the AV required to rendezvous with the Lagrange points. The injection AV here will be slightly higher than in the previous case because control of the Lunar flyby will generally require arrival at the Moon at some point other than apogee of the transfer ellipse. Injection AV may range from 3150 to 3180 m/s. Rendezvous AV at the Lagrange points has not yet been determined, but is expected to be in the range from 400 to 700 m/s.

A third technique for establishing a spacecraft at the Lagrange points uses Weak Stability Boundary (WSB) trajectories similar to those proposed by Belbruno and Miller, and flown by the Japanese spacecraft 1 Iiten, for lunar capture missions. in this case, the spacecraft is injected on a very highly elliptical orbit from the Earth with an apoapsis at about 1,500,000 km. This apoapsis point is oriented in Earth-Moon-Sun space such that solar perturbations will cause the subsequent trajectory to flyby the Moon into an orbit similar the Moon's orbit, but with slightly different period. This orbit will periodically fly by the three Lagrange points which arc at Lunar distance from the Earth. At these Lagrange point flybys, the spacecraft may rendezvous with the Libration point for a AV on the order of 370 m/s (1 Iellings). Injection onto the initial eccentric Earth orbit will require a AV from the 200 km circular low earth orbit of about 3200 m/s.

In each of these cases, some AV will be required for correction of injection errors and for other navigation functions. Since all of these options launch onto similar orbits, the AV for correction of injection errors will be comparable. Other navigation AVS may vary between the options, but should be small (<<10 m/s) in all cases. The injection errors will primarily be a function of the launch vehicle final stage guidance capability. These may be grossly broken into two cases - spin-stabilized stages (usually solid propellant) and 3-axis stabilized stages (usually liquid propellant) - with the former displaying larger errors than the latter. Because of the short flight time of these initial orbits to the Lagrange points or to the Moon (about 3 days), it may be expensive in propellant, and operationally difficult, to correct injection errors. Therefore, options arc being considered for injection into an interim orbit which would allow several additional days to correct inject ion errors and provide leverage for the correction maneuvers.

Table 1 summarizes these AV requirements, but this is not the end of the story for comparative evaluation of these techniques for getting to the Lagrange points.

Table 1. Summary of AV Requirements.

	Injection ΔV (m/s)	**Navigation ΔV (m/s)**	**Rendezvous ΔV (m/s)**	**Total AV (m/s)**
Direct	3135	TBD	830	**3965**
Lunar Flyby	3150-3180	TBD	400-700	3550-3880
WSB	3200	TBD	370	**3570**

Finally, the paper will look at some specific launch vehicle options from the U.S. and foreign stables of launchers which may be applicable to the SAGITTARIUS mission to see how their use may affect the selection of one of these methods of reaching the Lagrange points.

This abstract has not mentioned methods for reaching L1 and L2. If time permits, results for reaching these points will be included, but this area may have to wait for a later paper.

References

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